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ERAD: A Graph-Based Tool for Energy Resilience Analysis of Electric Distribution Systems

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Summary

Understanding the impact of extreme events on people's ability to access energy is crucial for designing resilient energy systems. In the event of a disaster, damage to the electric system and related infrastructure (e.g., downed power lines, flooded equipment, hacked communication systems, damaged roads, etc.) can impact people's access to critical services, including not just electricity but also shelter, food, healthcare, and more. There is a key need to understand such impacts better and evaluate options to improve energy resilience. The Energy Resilience Analysis for Electric Distribution Systems (ERAD) tool is a free and open-source software package designed to help researchers and decision-makers analyze and improve energy system resilience.

Statement of Need

Much of the past work in evaluating energy resilience has looked at historical data. For instance, Alper (2021) used historical power outage complaint calls in New York City to understand heat vulnerability, Flores et al. (2023) used satellite images to understand the impact of winter storms in Texas. In another example, Brockway et al. (2021) showed how existing grid infrastructure constraints may hinder the ability of communities to charge electric vehicles and their access to distributed energy resources by looking at the geospatial intersection of demographics and grid hosting capacity data. ERAD instead provides a way to look ahead at possible future outages and service access challenges. ERAD also offers the unique feature of assessing access to multiple services under multiple disaster event scenarios.

Many of the software tools developed for a forward-looking understanding of grid resilience have been focused on the bulk power system. For example, Panteli et al. (2016) used fragility curves to assess the impact of extreme events in transmission system components, Liu et al. (2017) developed resilience assessment indices to understand the impact of multiple transmission line outages, Wang et al. (2020) proposed a resilience-constrained economic dispatch model for bulk system. These studies miss geospatial granularity to enable understanding of extreme events on critical service access or outage impacts at the neighborhood scale, let alone the individual customer scale. Unlike existing resilience-focused tools that focus on transmission resilience, ERAD enables capturing these local effects at the neighborhood level or even down to the customer level.

There have been some recent efforts that consider resilience at the distribution system. For instance, the REPAIR tool (Moreira et al., 2021) optimizes distribution system expansion planning considering both routine operations reliability and resilience to extreme events. However, it requires users to supply outage rate information and does not consider any energy metrics or look across critical services. The ReNCAT tool (Wachtel, Melander, & Hart, 2022) does consider multi-service-based equity using the social burden metric introduced in Wachtel, Melander, & Jeffers (2022), however it only considers microgrids as a resilience strategy and its optimization-based approach may struggle to scale to the very large regions ERAD can evaluate. ReNCAT also currently requires the .Net framework (nominally under the Windows operating system) and though open source, does not currently maintain a publicly accessible code repository to enable outside contributions or issue reporting. Both REPAIR and ReNCAT also require exogenous equipment damage risk data and patterns. In contrast, ERAD endogenously models damage patterns; computes a range of energy metrics, and enables open engagement in development through github.com.

Implementation Overview

ERAD is a free, open-source Python toolkit for computing energy resilience measures in the face of hazards like earthquakes and flooding for distribution systems. It uses graph-based analysis to perform computation down to the individual households. Users start by defining hazard models either manually or using historic extreme events. Next, they define all distribution system assets of interest. Outage scenarios in ERAD are generated based on Monte Carlo samples across the individual equipment survival probabilities. Finally, ERAD computes a range of energy metrics, including outage probability, outage duration, and outage impact on critical services.

ERAD is now part of the Grid-Data-Models (GDM) ecosystem. This integration enables ERAD to run resilience analyses directly on GDM-based distribution systems, improving interoperability with other distribution-focused tools and streamlining the development of automated workflows.

For outage simulations, ERAD uses asset fragility curves (Baghmisheh & Mahsuli, 2021; Bennett et al., 2021; Buriticá et al., 2017; Jeddi et al., 2022; Indranil Kongar et al., 2014; I. Kongar et al., 2017; Mo et al., 2017; Williams et al., 2020) which are functions that relate hazard severity to survival probability for power system assets including cables, transformers, substations, roof-mounted solar panels, etc. (Cirone, 2013; Farahani et al., 2020; FEMA, 2020; Rajabzadeh & Kalantar, 2022; Sánchez-Muñoz et al., 2020). Outage scenarios are then generated based on Monte Carlo samples across these individual equipment survival probabilities.

Example Usage

ERAD has been used as part of multiple high-impact research efforts. Specifically, it was used to analyze energy access to critical services for 8 neighborhoods in the city of Los Angeles as it transitions to a 100% renewable energy future as part of the LA100 Equity Strategies project (Anderson et al., 2023). For transmission distribution cosimulation after a flooding disaster, ERAD has also been used to generate distribution system outage scenarios as a part of North American Energy Resilience Model (Donde et al., 2023) studies.

Next Steps

Future development will focus on expanding the tool's capabilities to simulate additional threats such as storms, heat waves, and cold spells, while also enhancing the efficiency of result visualization.

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